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Title:	White Source n-gamma Coincidence Measurements of gamma-Production Cross Sections at LANSCE
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White Source n-γ Coincidence Measurements of γ-Production Cross Sections at LANSCE

Kickoff Meeting Team Presentation

Keegan J. Kelly
Matthew J. Devlin, John M. O'Donnell,
Mark Paris, and Eames Bennett

Outline

- Team Introductions

- Technical Presentation
  - Motivation
  - Other methods
  - Proposed method
  - Proof of Concept
  - Timeline and milestones

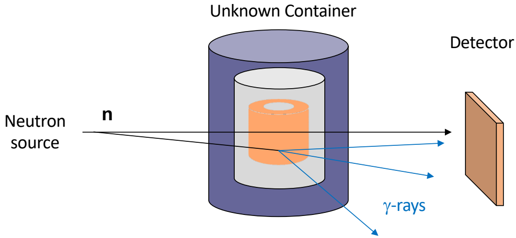
- Other items to discuss
  - LCP
  - TRL
  - Leveraging of existing technology
  - Reporting and Communications

Project Team Introductions

- Keegan Kelly, PI
  - Heavily involved in prompt fission neutron spectrum (PFNS) measurements at WNR FP15L at LANSCE with the Chi-Nu experiment
  - PI of LDRD-ECR and ER projects to investigate and develop neutron scattering measurement techniques
- Matthew Devlin, Co-I
  - PI of Chi-Nu experiment
  - GEANIE measurements of inelastic scattering and (n,2n) reactions
- John O'Donnell, Co-I
  - Heavily involved in Chi-Nu PFNS measurement and analysis
  - Wrote and developed the Universal Analysis Code (UAC) used for analysis of data from Chi-Nu and neutron scattering data
- Mark Paris, Co-I
  - World-leading expert in evaluation of light-ion nuclear data evaluations
  - Evaluation results are fed directly into the potential ENDF/B libraries
- Eames Bennett, PD
  - Experience in Chi-Nu and neutron scattering measurement and analysis
  - One of the POCs for LDRD-funded neutron scattering analysis

Project Motivation: Active Interrogation

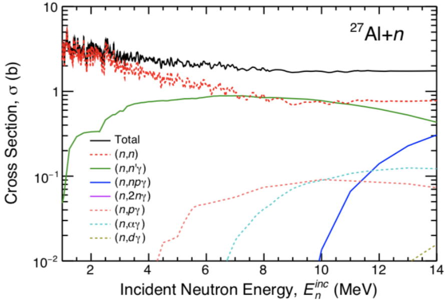
- n-Irradiate sample of interest
- Observe emitted γ spectrum

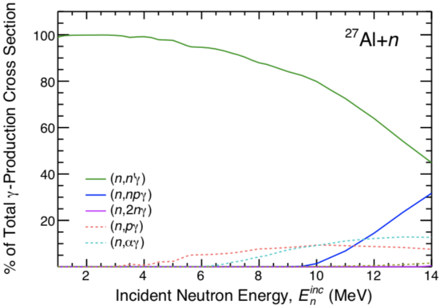


- γ-ray production is the common item of interest
- Inelastic n scattering cross sections are frequently the strongest contributors to γ-production cross sections
- Effectively no information on the correlated n-γ distributions
  - Not sufficient to just understand the scattering cross sections
- n transport is equally important for understanding the results

Measure correlated n-γ data to extract γ-emitting inelastic neutron scattering cross sections on ^{27}Al, ^{28}Si, and ^{16}O

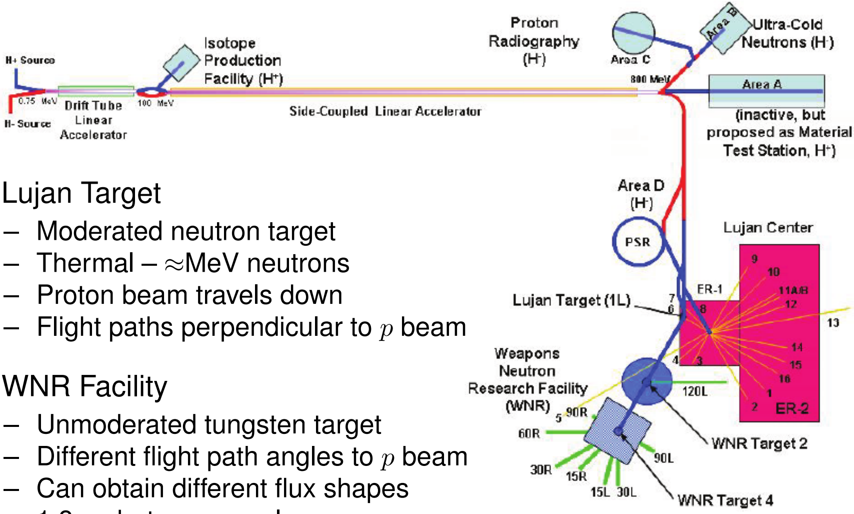
Most of the γ-prod XS is in (n,n')





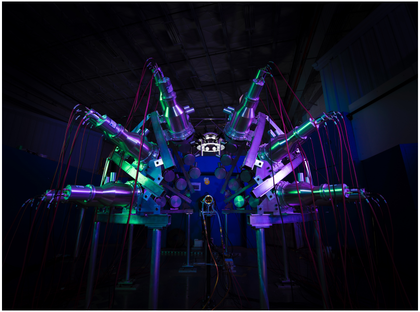
- γ-only measurements typically have poor E_n^{inc} resolution
- n-only measurements get cross section only (no γ info)
- Dual n-γ measurements are needed for cross section, γ production, and neutron transport
- Sensitive to all n-γ producing reactions

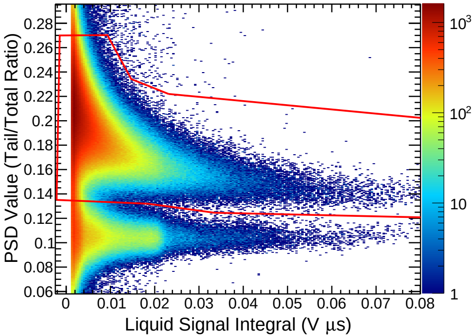
The LANSCE Facility: Pulsed White n Source

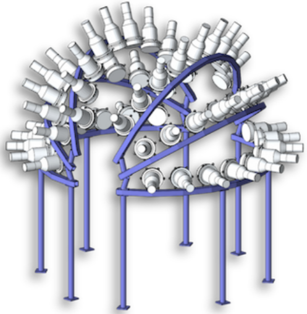


- Lujan Target
  - Moderated neutron target
  - Thermal – ≈MeV neutrons
  - Proton beam travels down
  - Flight paths perpendicular to p beam
- WNR Facility
  - Unmoderated tungsten target
  - Different flight path angles to p beam
  - Can obtain different flux shapes
  - 1.8 μs between p pulses

Properties of the Liquid Scintillator Array

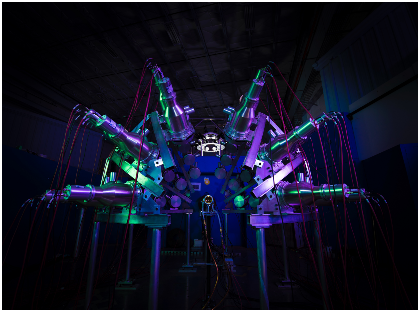


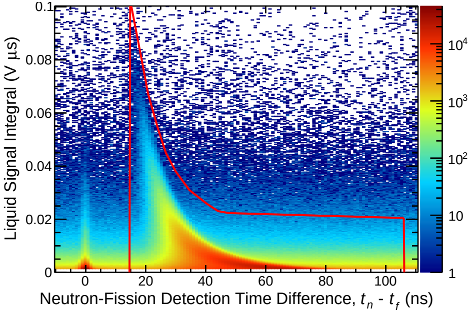


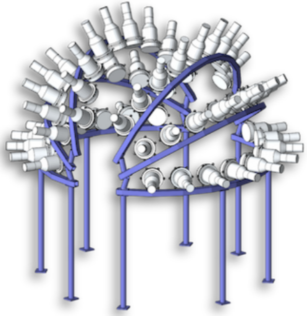


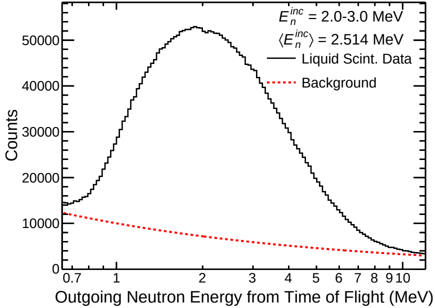
- Span θ = 30–150° at 15° increments
- Six angles in ϕ, ≈10% of 4π
- PSD for n-γ separation
- ≈1 ns time resolution
- Allows for mapping of n-γ dist.

Properties of the Liquid Scintillator Array

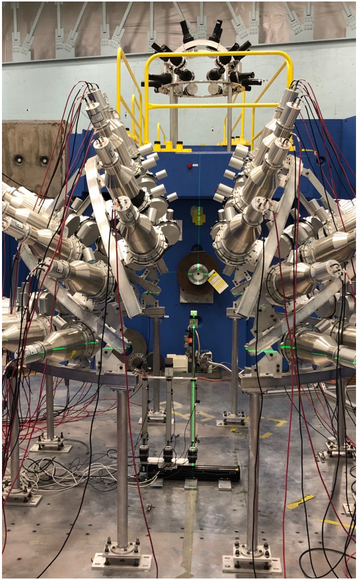


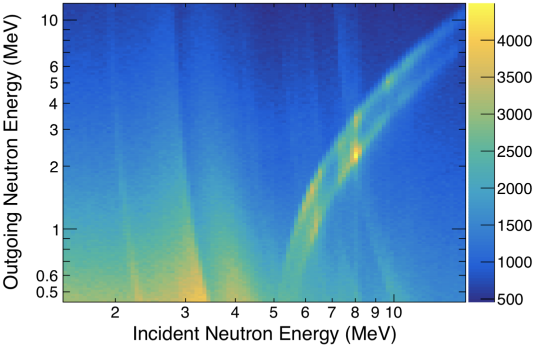






Demonstration Measurement: Natural Carbon





- Use t_γ-t_0 to get E_n^{inc}
- Use t_n-t_γ to get E_n^{out}
- Observe γ-coincident neutrons, with target and random coincidence backgrounds

Random Coincidence Backgrounds Eliminated

- Random coincidence rates derived form Poisson probabilities for *uncorrelated* detection rates †
  – true coincidence rate must be low
- Calculate the total probability for:
  1. Detecting a γ at time t_γ
  2. Not detecting n over coinc. time $t_n - t_\gamma$
  3. Detecting n at time t_n

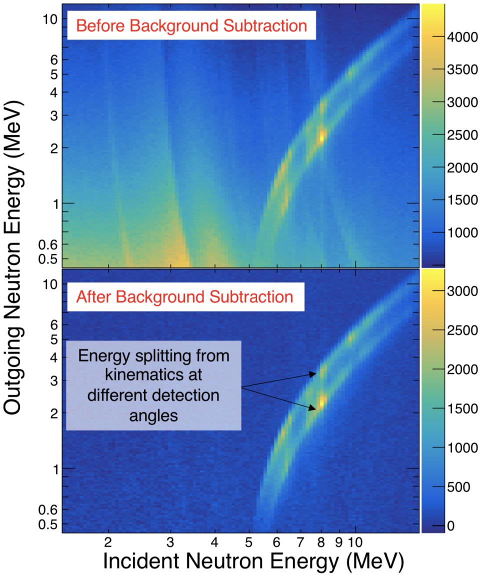
$$\text{Coinc. Rate} \quad = \quad r_b = r_\gamma r_n \Delta_t$$

$$\Rightarrow \quad b = \frac{\gamma n}{N_{t0}}$$

with $\gamma, n =$ counts

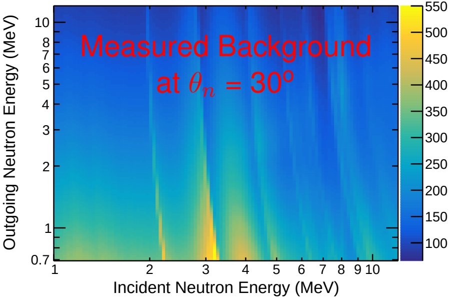
- Works remarkably well here, but what are the backgrounds?

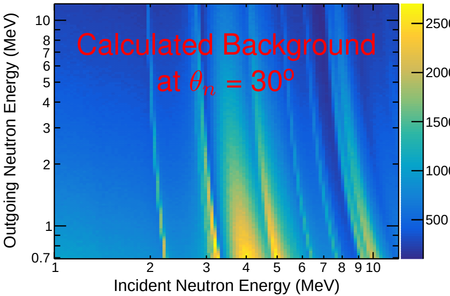
†O'Donnell, NIMA **805** (2016) 87



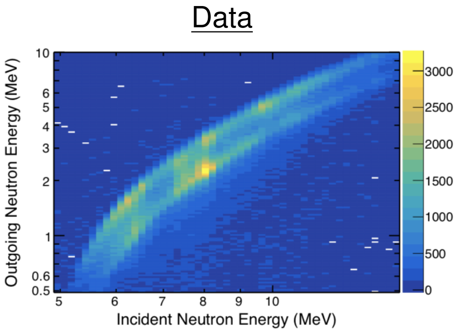
Backgrounds from γ-Anticoincident Neutrons

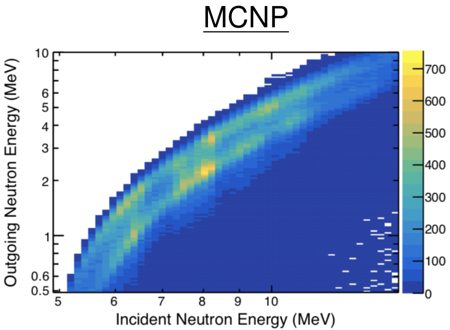
- The elastic scattering ^{12}C(n,n) reaction is a likely source
- Do a simple Monte Carlo calculation for this background:
  - Sample incident neutrons from WNR FP15L flux shape
  - Calculate E_n^{out} from sample E_n^{inc}, convert to TOFs
  - Vary TOFs according to random γ timing, recover new $E_n^{inc'}$ and $E_n^{out'}$
  - Fill histogram with counts = $\sigma(E_n^{inc})$
- Possible to extract cross sections from this background?...maybe...





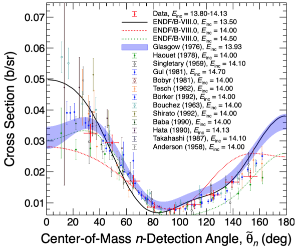
MCNP Simulations of Carbon Data



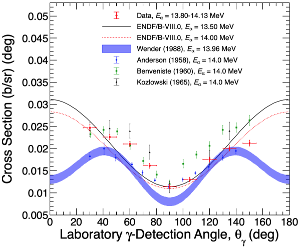


- Chi-Nu experiment analysis relied heavily on MCNP simulations
- MCNP can guide n-γ detector efficiencies
- Number of internal scatters can be investigated
- Understanding neutron interactions with the environment is important

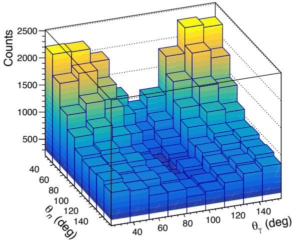
Extract n, γ, and Correlated n-γ Distributions



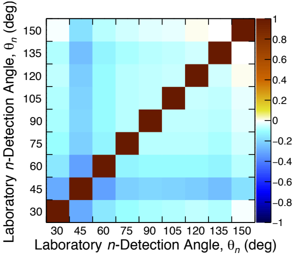
(a)



(b)



(c)



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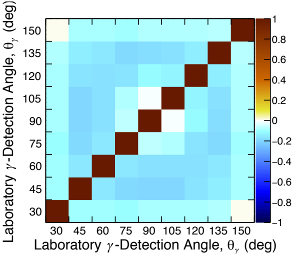
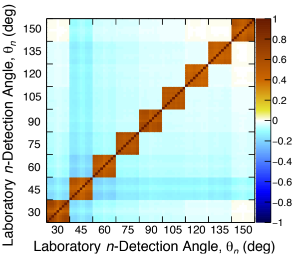
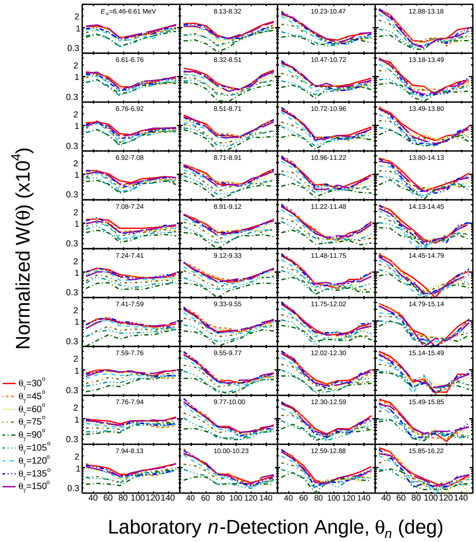


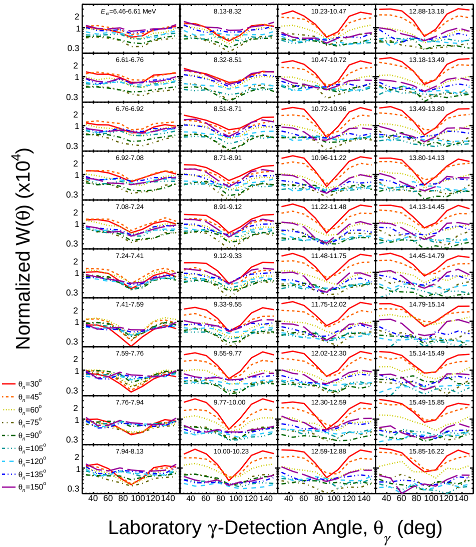
(e)



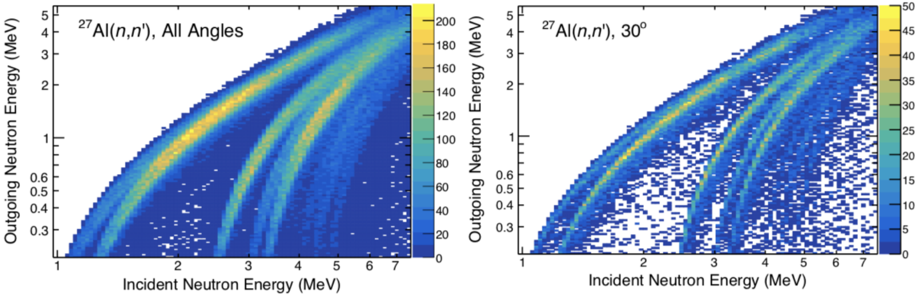
(f)

Corr. n-γ Distributions for Wide Range of E_n^{inc}





Goal and Expected Al Yield

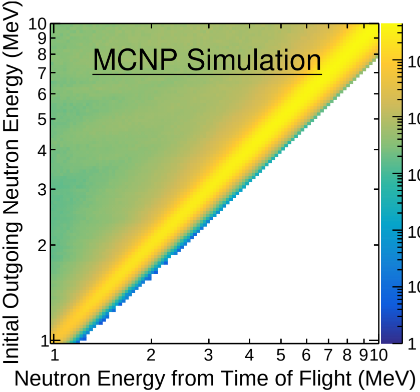


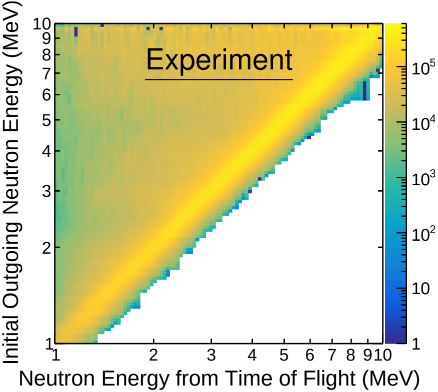
- Use γ-coincident n yields to extract γ-production cross sections
- Initially assume level decay branching ratios from each excited state
- Can be used to cross check data γ-anticoincident data, and n-only MCNP simulations

And now for a couple of interesting analysis details that we hope to exploit for the analysis of these data

Obtain 2D n Efficiency from ^{12}C(n,$n'_1\gamma$)

- Typical treatments of detection efficiency work poorly for neutrons
- Need complete description of n interactions with exp. environment
  - Especially for smooth distributions (e.g., high level density scattering)
- This was handled with MCNP for Chi-Nu PFNS measurements
- Could be more accurately done with measurements

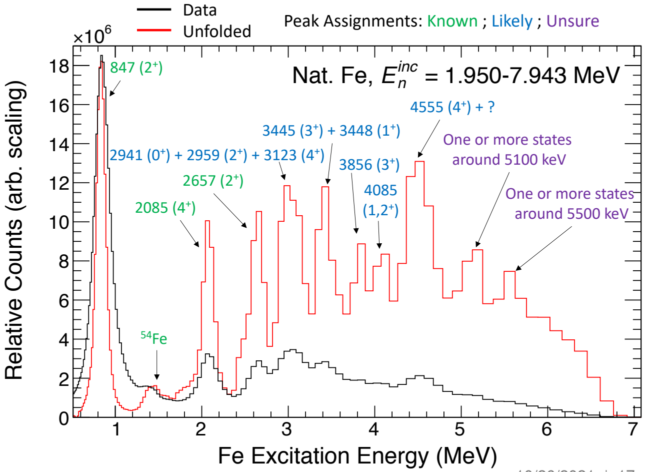




Iterative Unfolding to Isolate Excited States

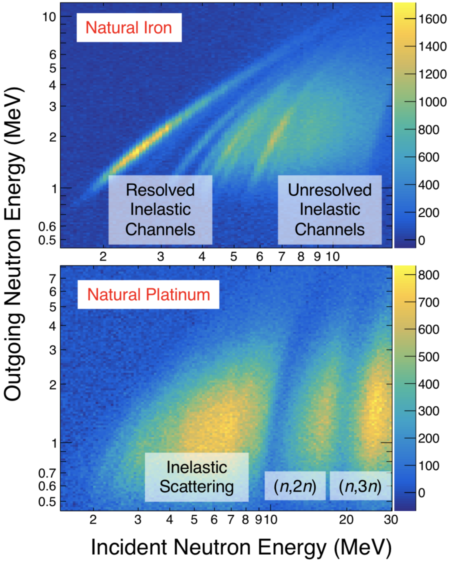
From last week: $m_{\alpha|\beta}^{(n+1)}(E) = \dfrac{m_{\alpha|\beta}^{(n)}(E)c_\alpha(E)}{\sum_{i=1}^{N}\mathcal{R}(E,E_i)m_{\alpha|\beta}^{(n)}(E_i)}$

- Clearer view of states in data
- Informs treatment of n response
- Clarifies expected γ rays
- Confirms inelastic state populations

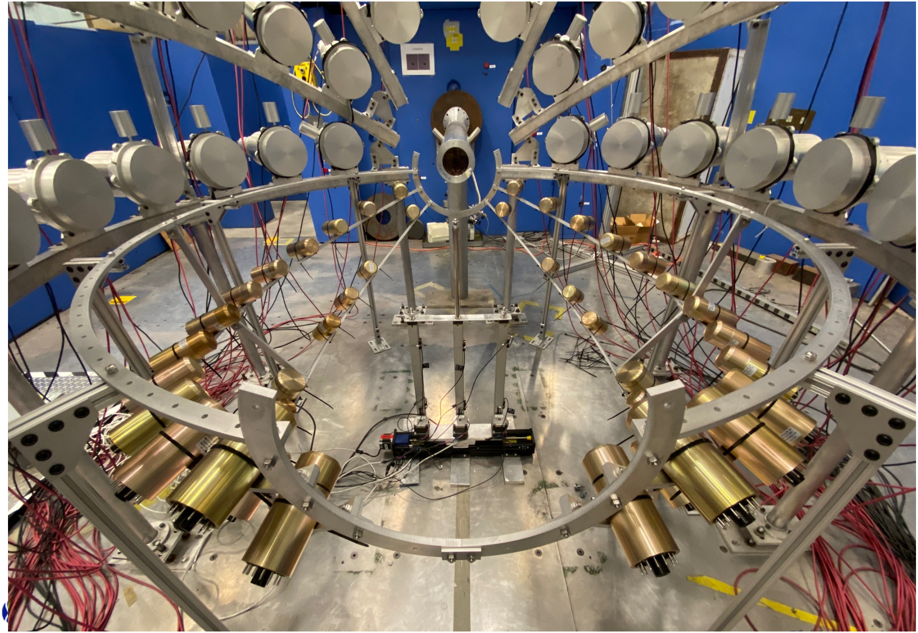


Sensitive to *All* n-γ Producing Reactions

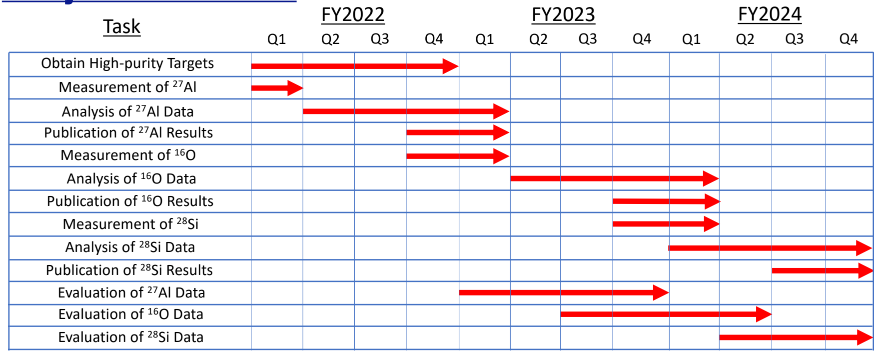
- Fe levels are reasonably dense
- The liquid scint. time resolution allows for ^{56}Fe low-lying state separation
- Natural Pt shows inelastic scattering, (n,2n), and (n,3n) reactions, with separation
- Elastic scattering data also exist from these measurements
- Potential for correlated measurements of these different cross sections



Experimental Setup for Aluminum Measurement



Project Timeline



- Proposed milestones are repetitive for each proposed target:
  - Obtain data from each target near start of each FY
  - Analyze data during same FY as measurement
  - Work towards publication near end of FY and start of next FY
  - Include data in evaluation as they are available (typically before
- Potential for final meas. to use only CLYC detectors may arise

Other Items to Discuss

- LCP, deliverables, work scope, and milestones
  - Discussion of acceptance criteria for milestones?
- Leveraging existing and developing detection and sample setups, as well as analysis techniques developed under LDRD funding
- Team consists
  - 3 more senior staff members (Co-I's)
  - 1 early career scientist (PI)
  - 1 postdoc
- Technical Readiness Level (TRL)
  - Starting: 8/10, system demo, nearing complete analysis path
  - Ending: 10/10, system complete and in production use
- Reporting requirements
- Constraints (beamtime availability)
- Risks and opportunities
- Communications plan and possible stakeholders